Oakley Sound Systems

Euro Rack Series

Classic VCA issue 2

Discrete Core Voltage Controlled Amplifier

Builder's Guide

V2.0.0

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Introduction

This is the Project Builder's Guide for the issue 2 Classic VCA 3U module from Oakley Sound. This document contains a basic introduction to the board, a full parts list for the components needed to populate the board or boards, and a list of the various interconnections.

For the User Manual, which contains an overview of the operation of the unit and the calibration procedure, please visit the main project webpage at:

http://www.oakleysound.com/vinvca.htm

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at the project webpage or http://www.oakleysound.com/parts.pdf.

For general information on how to build our modules, including circuit board population, mounting front panel components and making up board interconnects please see our generic Construction Guide at the project webpage or http://www.oakleysound.com/construct.pdf.

The prototype Classic VCA module using a 10HP wide Scheaffer panel. Note that on this module the sockets are on the right of the pots. The Krisp1 manufactured version has the pots to the left and fitted with an 8HP wide panel. The functionality is the same however.

The Classic VCA issue 2 PCB

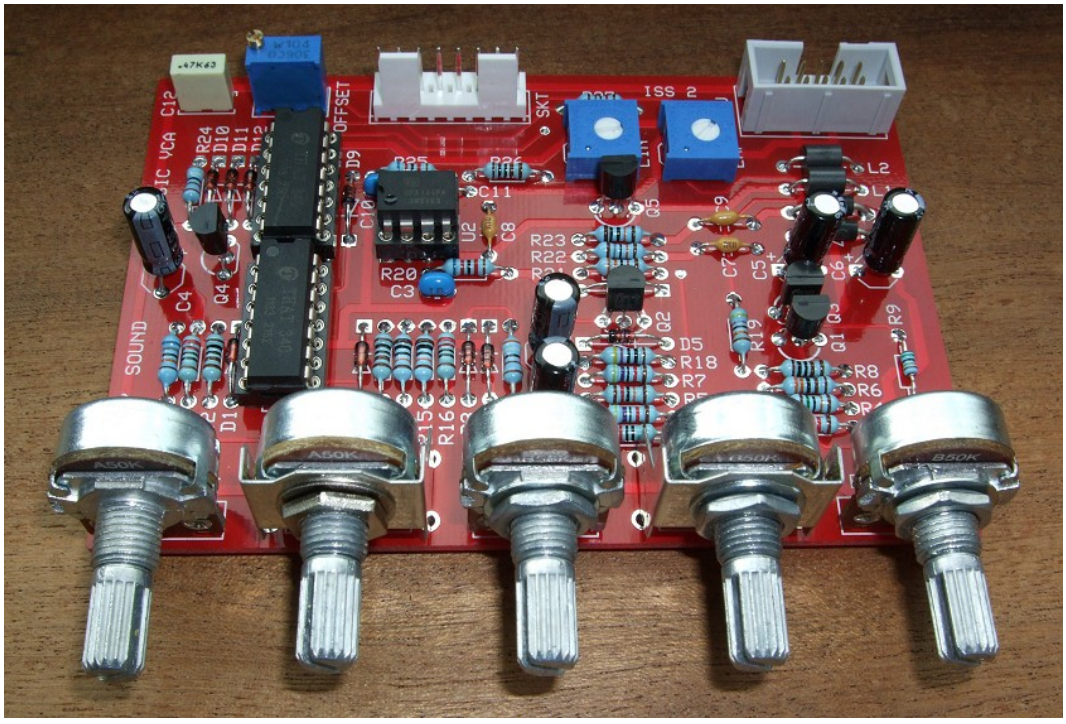
This is one of our smaller format PCBs. We are expecting most builders to be using a smaller 3U Euro sized panel with this module. The pots are specified as Alpha/ALPS 16mm types. The pot spacing on this module is 21mm (0.827”).

The size of the board is 102mm high by 69mm deep. The board is fitted to the front panel by the pots, two of which use special pot brackets.

The input and output sockets are wired to the board via an eight way 0.1” Molex or MTA interconnect. This makes removing the board from the panel very easy. It also offers the possibility of connection to a socket board like our 5U VCO and other modules. However, at this moment in time we have no plans to release a socket board for this particular module.

Issue 2 differs from issue 1 in several ways:

1. The MOTM/Oakley/Frac power header is now gone.
2. The ineffectual NULL trimmer and associating components have been removed.
3. The obsolete SSM2220 PNP array has been replaced by another THAT340 array.
4. Additional power supply filtering has been added.
5. Reverse polarity protection has been provided for the power supply inlet.
6. PCBs have red solder mask to match our other current eurorack modules.
7. The PCB is 10mm less deep.



The issue 2 Classic VCA. This one has been built with 16mm Alpha pots from Banzai and uses a Molex 0.1” KK header for the sockets connection.

Classic VCA issue 2 Parts List

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at the project web page or http://www.oakleysound.com/parts.pdf.

The components are grouped into values, the order of the component names is of no particular consequence.

A quick note on European part descriptions. R is shorthand for ohm. K is shorthand for kilo-ohm. R is shorthand for ohm. So 22R is 22 ohm, 1K5 is 1,500 ohms or 1.5 kilohms. For capacitors: 1uF = one microfarad = 1000nF = one thousand nanofarad.

To prevent loss of the small '.' as the decimal point, a convention of inserting the unit in its place is used. eg. 4R7 is a 4.7 ohm, 4K7 is a 4700 ohm resistor, 6n8 is a 6.8 nF capacitor.

For Alpha or ALPS pots: A = logarithmic or audio taper, B = Linear taper

Resistors

All 5% carbon 1/4W or better. 1% metal film types preferred.

220R	R1, R11, R16
470R	R18
1K	R13, R12, R8, R26
3K3	R6
3K9	R17, R24
18K	R27
33K	R21
47K	R2, R3, R7
62K	R20, R25
100K	R23, R14, R15
120K	R5
150K	R4
180K	R22
470K	R19
680K	R10
1M5	R9

Capacitors

18pF 2.5mm low-K ceramic	C3, C10
100nF axial multilayer ceramic	C7, C8, C9, C11
470nF, 63V polyester	C12
2u2, 63V electrolytic	C5, C6
10uF, 63V electrolytic	C1, C2, C4

Discrete Semiconductors

1N4148 signal diode	D1, D2, D3, D4, D5, D6, D9, D10, D11, D12
1N4004 rectifier diode	D7, D8
BC550 NPN transistor	Q3
BC560 PNP transistor	Q1, Q2, Q4, Q5

Integrated Circuits

OPA134PA single op-amp	U3
THAT340P NPN/PNP array	U1, U3

Trimmers

100K multiturn trimmer	OFFSET
100K 6mm horizontal trimmer	EXP, LIN

Potentiometers

50K logarithmic Alpha 16mm pot	DC_INPUT, AC_INPUT
50K linear Alpha 16mm pot	GAIN, EXPO_CV, LIN_CV
Pot brackets	Two off

Miscellaneous

2 x 5 0.1” header	PSU

Note: If using a boxed header for PSU then ensure to mount the header so that the notch in the header's outer case faces away from the front panel. That is fit pin 1 of the header, usually marked with a little triangle on the header, towards the bottom of the board.

0.1” 8-way Molex or MTA header	SOCKETS – board mounted
0.1” 8-way Molex or MTA housing	SOCKETS – wire harness
Leaded ferrite beads	L1, L2
Knobs to fit 6mm shafts	Five off
3.5 sockets	Five off
DIL14 pin IC sockets	Two off
DIL 8 pin IC socket	One off

Hook up wire (26awg) in several different colours

Circuit description

The Oakley Classic VCA is based around the old ARP module 4019. This module was built on an incredibly tightly cramped circuit board which was then securely potted, with a very hard epoxy compound, into a small plastic box. The various interconnections were made to some thin gold plated legs that stuck out from the hard epoxy on the underside. It is almost impossible to remove the circuitry from its hard plastic shell and all encompassing resin. I suppose this was mostly down to Alan Pearlman's previous history in making op-amps for the aerospace industry – enclosing circuits like this would make them less likely to drift with temperature and not be affected by surrounding humidity. However, one might also think that they did it to keep out the prying eyes of their competitors.

Later versions of the 4019 used soft and rubbery silicone to pot the circuitry into its shell with only a thin layer of epoxy on the underside to seal it all in. These types are easier to repair since it is now possible, with some care, to remove the delicate circuitry from its shell and potting compound. Various folk have since reverse engineered this circuit and it can be found in various places on the internet.

Interestingly the very first 2600 synthesisers had the 4010 VCA module installed. I have not been able to find out much about this particular module suffice to say that it was physically smaller and probably less reliable than the later version. The fact that it was smaller surely meant that it contained less circuitry compared to its successor.

Purchasers of the Oakley Classic VCA PCB will be able to obtain a copy of the schematic. The circuit itself looks pretty unusual but it can be split up into two smaller parts to make understanding it a bit easier.

The first part of the schematic we will look at is the CV processing. This takes the two CV inputs, processes them and turns them into a small current that will control the gain of the VCA core. You can find the CV processing circuit on the left hand side of the schematic.

The linear and exponential inputs are processed separately. The top left hand circuit, based around Q1 and Q3, deals with the exponential input. The CV input is controlled by its own level pot, EXPO_CV, and is configured as the usual voltage divider. As the wiper moves up and down a proportion of the input voltage is fed into R2.

Q1 and Q3 form a standard ARP style exponential convertor. The precise actions of this go beyond this simple document, but it can be shown that for every 18mV increase in Q1’s base voltage we double the current going through Q3. Q3 draws this current from the VCA core of which we will discuss later.

EXP is a trimmer, a set and forget type of device, and allows adjustment of the maximum gain of the VCA from the exponential CV input.

The linear input is also controlled by a pot, this time LIN_CV, and it is passed via R3 to a summing node at the junction of R5, R7 and R18. This node is held at around 0V by the actions of Q2 and D5. Q2 and Q5 form an old style DC coupled amplifier. Q2 does all the amplification while Q5 provides some level shifting and output buffering. Negative feedback is

provided by the trimmer LIN and R7. LIN therefore provides some adjustment over the gain of the amplifier block and thus sets the sensitivity of the linear CV input.

Note the GAIN pot, this is one of the front panel pots. The wiper of this pot can go from +12V to 0V. This voltage is turned into a current by R5 and injected into the summing node. R1 and C1 provide some low pass filtering of the power supply that is used to feed the GAIN pot. Both the CV input and GAIN pot control the output voltage of the little amplifier circuit.

R27 and the NPN transistor, U3 (pins 1, 2, 3), then turn this output voltage into a current which, in tandem with Q3, controls the VCA core.

Now let us look at the VCA core itself. This comprises of the two transistor arrays, U1 and U3, and the surrounding circuitry. It can be found in the middle of the schematic.

The basic topology of the VCA core is fairly standard. It is a transconductance amplifier built almost entirely from discrete transistors. The unusual thing about it, at least as far as most synth designs go, is that it is upside down. The input transistors, U1 pins 5, 6, 7 & 8, 9, 10, are PNPs. Most designs use NPNs. However, let's put that aside and see if we can work out how it works.

The signal enters the VCA via either, or both, of the two socket connections, AC_IN and DC_IN. They are both identical except for the addition of a 470nF capacitor, C12, on the AC_IN. This capacitor acts to block steady state voltages (DC) and very low frequencies. In other words it acts like a high pass filter. The cut-off varies a little with the position of the AC_INPUT pot, but it is approximately 10Hz.

R14 and R15 carry their respective signals to attenuate (reduce) and sum together at R16. The voltage across R16 being a tiny fraction, approximately 0.2%, of what it was at the socket inputs. Both inputs are applied to the right hand input PNP transistor. The other input transistor, the left hand one, is simply connected to a very low voltage that is generated by the OFFSET trimmer, R10, R11 and R12. We use this trimmer to manually balance the left and right sides of the VCA core.

The voltage supply to the transconductance stage is fixed by diodes. The series combination of D10, D11 & D12, provide a steady +1.8V for the top of the circuit. While the series combination of D3 & D4 provide a steady -1.2V for the bottom of the circuit. When current passes through a diode it tends to have 0.6V across it. +1.8V and -1.2V may appear to be a very small range of supply voltage for a module that can handle nearly +/- 10V input signals. But remember the actual input transistors will only be working with that tiny fraction of the input signal to prevent them from distorting the signal. C2 and C4 provide some high frequency filtering for the low voltage points.

U3 (pins 5, 6, 7 & 8, 9, 10) and Q4 make a special circuit which engineers call the Wilson current mirror. It is a clever little design and is found in many different circuits. The Wilson current mirror is a programmable current source. It is programmed by the CV processing circuitry which we discussed earlier. Any current drawn out from the collector of transistor U3 (pins 5, 6, 7) by the CV processing circuit is then replicated by the mirror and provided to the circuitry connected to the collector of Q4. Thus the input transistors of the VCA core are supplied with a current that is controlled by the CV signals.

The two NPN transistors from U1 (pins 12, 13, 14 & 1, 2, 3), along with U3 (pins 12, 13, 14) and D9 act as another current mirror. The current drawn down by each NPN transistor in U1 will be the same due to the actions of the mirror. However, when an input signal is applied to one of the input PNP transistors this equality of current is challenged. But the current mirror will do its very best to maintain equilibrium so any 'excess' current is taken away by the op-amp U2. This current is the VCA core's output signal and it should be reiterated that it is a current not a voltage. Indeed, if you were to slap your 'scope probe on this point you would see very little happening. The voltage remains, due to the actions of the op-amp, firmly stuck at around zero volts.

It should be noted at this point that the current output of the VCA core, the transconductance amplifier, is directly proportional to the current being supplied by Q4. After all this is where the input transistors get their current from in the first place. Remember that no significant current is actually taken from the input signal via the base of the PNP transistors. So if the output current is dependant on the current provided by Q4, then controlling this current allows us to control the gain of the whole transconductance amplifier. This is why our CV processing circuit is tied to the top current mirror of the core. It has direct control over the gain and this is what makes it a VCA.

The op-amp is configured as an inverting transimpedance amplifier, which is a 'current in, voltage out' device and essentially the opposite of a transconductance amplifier. A transconductance amplifier followed by a transimpedance amplifier make an amplifier, ie. 'voltage in, voltage out'. The 'gain' of the transimpedance amplifier is primarily set by R25. The output of the op-amp passes via R26 to the output socket of the module.

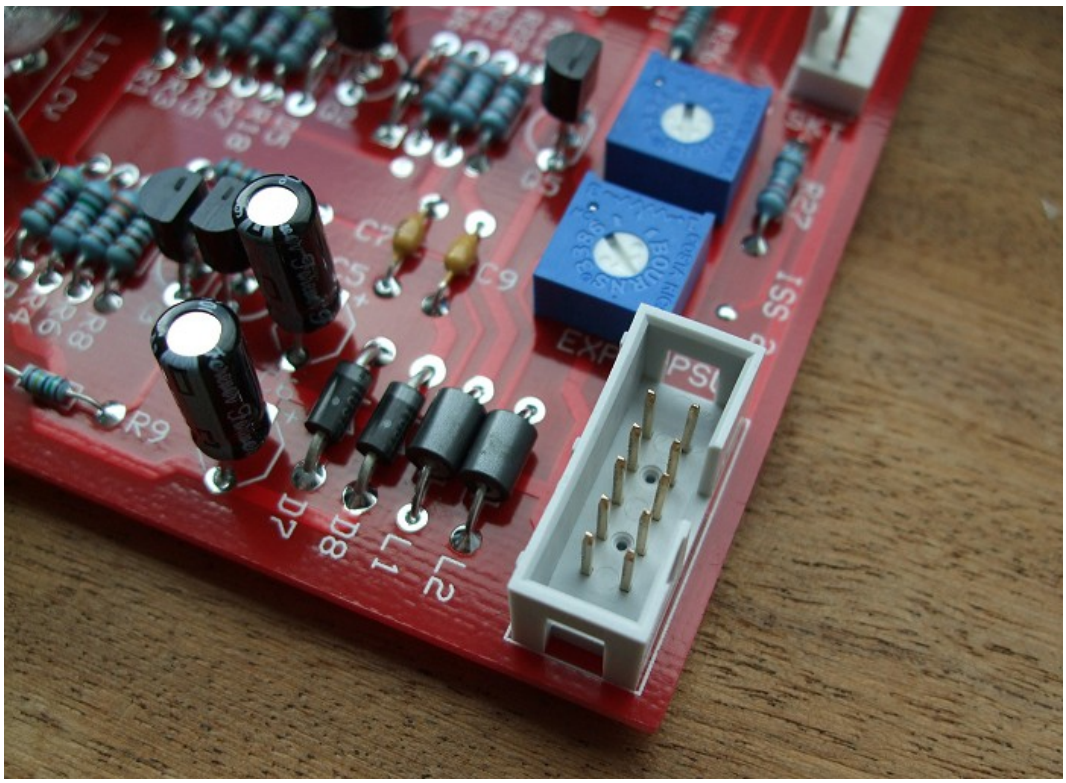
A standard transimpedance amplifier is just an op-amp and a resistor. This one looks more complex – its has two additional capacitors and an extra resistor. C3 and C10 both act to ensure stability of the circuit. No real life circuit is perfect, and without getting into the maths of it, unwanted characteristics of the components and board layout sometimes act to make the circuit unhappy. Typically this will mean it will oscillate when it shouldn't, or more commonly it will nearly oscillate when it shouldn't. The latter is called ringing and it is a resonance effect. In other words the circuit has a tendency to bounce around at a particular frequency when excited by an input signal.

When using a TL071 for U2 and not fitting any of the capacitors, the VCA would ring horribly at a very high frequency. This is way above human hearing but any ringing is not a good thing. Using all the values and the same op-amp that ARP used made the circuit very stable, ie. no ringing, but it reduced the overall frequency response so that it had a negative impact on the audio bandwidth of the VCA. This raised an interesting question regarding the frequency response of a real ARP2019 since the drop in high frequency audio is audible.

Since I would like my VCA to have the full audio bandwidth then the capacitor values have been optimised for this issue of the PCB and are considerably smaller in value to those chosen by ARP. I have also chosen an OPA134 op-amp for U3. Whether this has a huge difference in audio performance when compared to a TL071 is debatable but the OPA134 is certainly a very capable device.

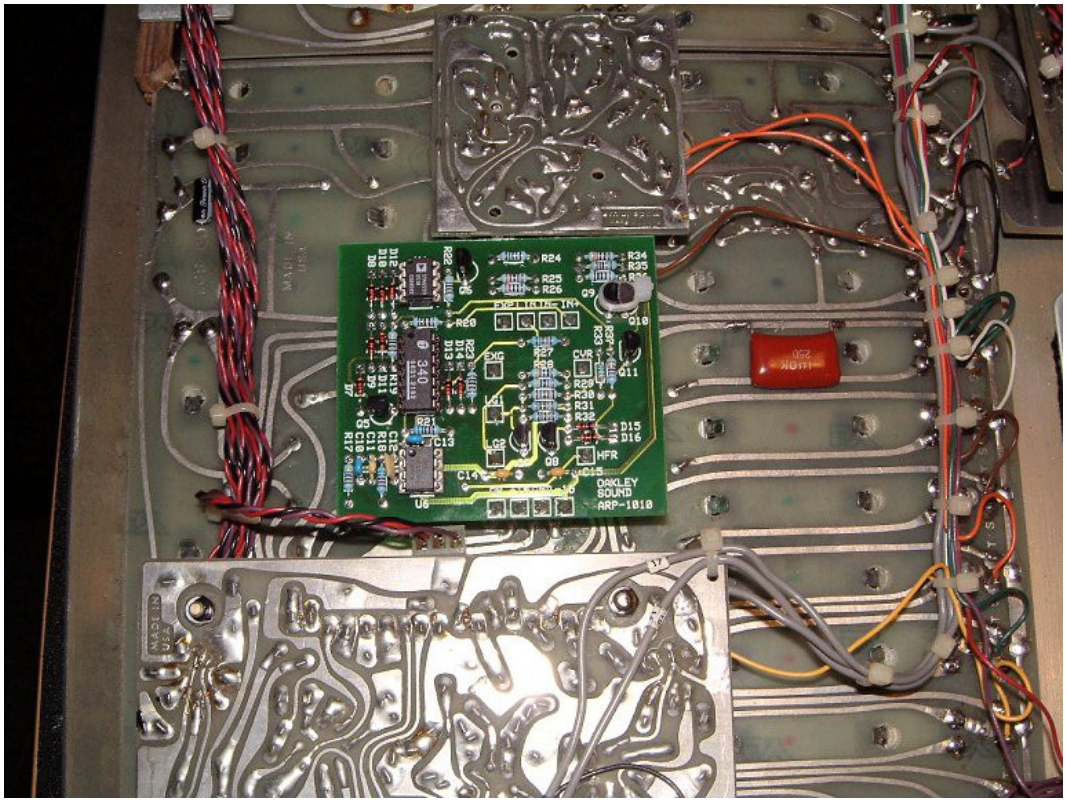
R20 and C3 provide the op-amp with equal resistances on both of its inputs. The inverting input 'sees' only R25 and C10 since the resistance of the transimpedance amplifier is so high one can normally ignore it.

Power is supplied via the usual 10 way Euro style power connector. As is the custom for Oakley modules, I have used ferrite beads to act as high frequency filters on the power lines. Decoupling at the point of entry is provided by C5 and C9 for the positive rail, and C6 and C7 for the negative rail. Additional decoupling is also provided elsewhere on the board by the other capacitors shown at the top of the schematic. All these capacitors keep the power supply clean of noise, and provide a reservoir for the little bursts of current that the circuit takes in normal operation. Diodes, D7 and D8, provide some protection to the module should the power supply be reversed. On reversal the diodes will pass current and clamp the supply to just over half a volt. It is hoped that this will create sufficient current so as to cause the power supply module to shut down and thus protect the module and the power supply.



The polarised boxed header that connects the power to the module. Note the orientation of the boxed header with the notch facing outward. The -12V connection, usually depicted with a red stripe, would be nearest to the bottom edge of the board.

The idea behind the Oakley Classic VCA module



This is very first version of the Oakley Classic VCA fitted to a real ARP2600C. This one off clone was built to replace a dead 'all epoxy' 4019 VCA module which in itself had replaced an older 4010 VCA module. Note the pin out placement to accommodate the smaller 4010 module.

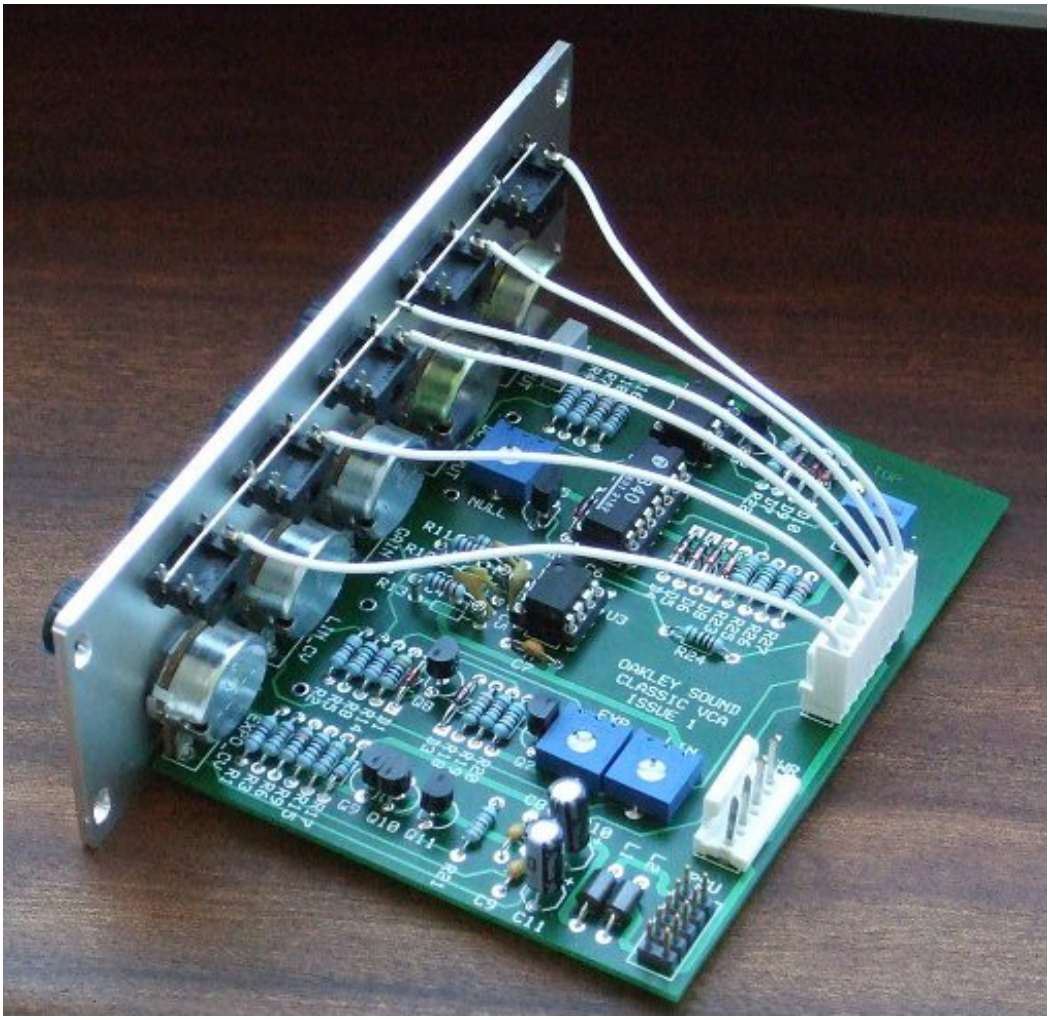
I later compared this 2600C to an early 2600P fitted with a standard 4019 module and the differences were negligible in all but the increased frequency response of the clone.

The large red polypropylene capacitor fitted to the underside of the main circuit board is a modification done to provide DC blocking to the VCA on one of its inputs. The ARP2600 is predominantly DC coupled, but this tends to unbalance the VCA since many of the VCO waveforms are unipolar, ie. all positive. This positive bias of the VCA input leads to thumping at fast attack and release settings. The capacitor removes the bias and allows for fast thump free sounds. The action of the red capacitor is much the same as the INPUT (AC) on this module.

Input and Output Connections

All audio and CV connections are via a eight way 0.1” header on the PCB called 'SKT'. This may be different to other Oakley PCBs you may have built. Doing it like this allows you to remove the board from the front panel easily, and allows the potential for additional socket boards to be used in any future production run of the board.

You don't have to use a header in your PCB, you can solder your wires directly to the PCB from the various socket lugs if you wish.



This the prototype Euro module in the exemplar 10HP wide panel with the sockets mounted to the right of the pots. This early version of the PCB design differs significantly from the production runs. Note that two types of power sockets have been fitted so it could be tested on both +/-12V and +/-15V systems. Note that the signal NC lugs of the sockets have yet to be connected.

How you wire your input and output sockets up will very much depend on your panel design and choice of sockets. I will only go into the details of wiring up the standard 3U high 10HP panel with the five 3.5mm sockets to the right of the PCB.

For my prototype I used Cliff jack sockets. I used these because they are relatively cheap and provide insulation between the module panel and the module ground. The module panel will be grounded or earthed via the rack casing. It is usually a good idea not to allow any local module ground to come into contact with the chassis at multiple points as this has the *potential* to cause ground loops and hums in your audio outputs.

Furthermore, as far as I can see it, most Euro rack systems are wired in such a way as to allow an additional ground pathway to occur whenever a patch cable is plugged from one module to another. However, since there has not been a chorus of complaints regarding multiple earth loops and hum problems, I think we can take it that it is not a major problem. The Oakley modular system circumvents this whole complicated issue by using a second ground connection to provide a panel earth on each module. Thus panels and local grounds are distinct except for at one point near the power supply.

If you have used the little Cliff sockets you will see that they have four connections. One is the earth lug or ground tag. The second is the signal tag which will be connected to the tip of the jack plug when it is inserted. The third and fourth tag are the normalised tags, or NC (normally closed) lugs. The NC lugs are each internally connected to the ground and signal tags when a jack plug is not inserted. These connections should be automatically broken when you insert a jack.

Most 3.5mm sockets with metal bushes have only one NC lug, that is these sockets will have just three connections. Their NC lug will be connected to the signal lug of the socket when no jack is inserted. Normally, when one refers to NC lugs we are talking about the one that connects to the signal lug and not the ground lug.

Pushing a jack plug into an unconnected socket and looking carefully at the various contacts will reveal the actions of the NC lugs.

Fit the five sockets onto the panel so that the all the socket's tags face left as you look at the rear of the panel, ie. away from the PCB.

In this module we are going to ‘common’ the sockets’ ground lugs. This means that the sockets’ earth lugs are going to be joined together so we only need one piece of insulated interconnection wire to ground all the sockets. I normally do this part of the wiring without the PCB or pots in place on the panel. I use thin uninsulated tinned copper wire, its just stiff enough so as to retain its shape. Solder a length of this solid core wire right across all the tags nearest to the panel. These are the earth tag, and its corresponding NC tag if you have them, on all the sockets. Trim off any excess wire that sticks out on either end. This single wire will eventually be connected to the printed circuit board via pin 3 of the SKT header.

If your chosen sockets do not have an earth NC lug, this is fine. Simply make sure that all your socket grounds are connected together.

Fit the Classic VCA PCB against the front panel if you haven't done so already. For my prototype I used Molex KK headers and housings to connect my module's sockets to the circuit board.

Use multistrand hook up wire to connect each socket lug to the relevant pin on the header. Keep your wires short but not too short and you can use as many different colour wires as you can – although I tend to use one colour because I'm a minimalist. There is absolutely no need to use screened cable for such short runs.

The connections to the signal and NC lugs of the sockets that go directly to the PCB are summarised in the table below. They are given in the order in which I would recommend that they be soldered.

Socket Name	***SKT Pin number***	***Lug Type***
INPUT (AC)	1	Signal
INPUT (AC)	5	NC
INPUT (DC)	2	Signal
INPUT (DC)	5	NC
OUTPUT	4	Signal
LIN CV	6	Signal
LIN CV	7	NC
EXPO CV	8	Signal
EXPO CV	7	NC

With the NC lugs you can simply connect the NC lugs of each pair of adjacent sockets together and take just one wire back to the header on the PCB. Do not connect the NC lug on the output socket to anything.

Finally Pin 3 is connected to the single uninsulated wire that joins the socket ground tags.

Once that is done, your module is ready for testing and calibration.

Testing, testing, 1, 2, 3...

Apply power to the unit making sure you are applying the power correctly. Check that no device is running hot. Any sign of smoke or strange smells turn off the power immediately and recheck the polarity of the power supply, and the direction of the ICs in their sockets.

Assuming everything is OK so far, it is time to apply an audio input. Use a signal like a triangle output from a VCO. Middle A, 440Hz is a good note to use. Turn down all the pots to their minimum setting and insert your triangle wave signal into INPUT (AC). Listen to the output signal from the VCA module. For the moment you should hear nothing.

Turn up the INPUT (AC) pot to full. Again, you shouldn't hear anything, but maybe you will hear a little triangle wave bleedthrough. Now slowly turn up the GAIN pot. If all is well this should behave like a volume control, increasing the level of the triangle wave as it is turned up.

Ensure that altering the INPUT (DC) pot should have no effect on the sound, but that INPUT (AC) behaves also like a volume control. It should seem that both INPUT (AC) and GAIN do the same thing. They do not of course, since INPUT (AC) is altering the signal level going into the VCA circuit, and GAIN is adjusting the amplification within the VCA's core.

Swap the input signal over to the INPUT (DC) input. It should be quiet again. Turning up the INPUT (DC) pot should bring back the signal.

There is a very good chance your circuit is working correctly if you have got this far with no problems. However, we still need to check a few other things and you'll need another signal source to do this. Connect a LFO or VC-LFO to the LIN CV input. Use a sine or triangle wave signal at a lowish frequency, say 1Hz or so.

Turn the GAIN down to about 50% and the LIN CV up. Listen to the resultant sound. It should be the triangle wave you can hear again, but it will plusate evenly up and down with LFO signal. You should hear it go up and down in volume once for every cycle of the LFO.

Now remove the LFO signal from the LIN CV socket and connect it to the EXPO CV socket. Turn up the EXPO CV pot and you should hear the same sort of pulsating sound. However, it should be slightly different, spending more time loud than quiet..

If all is well, then you have a working VCA module. Calibration details can be found in the User Manual.

Final Comments

If you have any problems with the module, an excellent source of support is the Oakley Sound Forum at Muffwiggler.com. Paul Darlow and I are on this group, as well as many other users and builders of Oakley modules.

If you can't get your project to work, then Oakley Sound Systems are able to offer a 'get you working' service. If you wish to take up this service please e-mail me, Tony Allgood, at my contact e-mail address found on the website. I can service either fully populated PCBs or whole modules. You will be charged for all postage costs, any parts used and my time at 25GBP per hour. Most faults can be found and fixed within one hour, and I normally return modules within a week. The minimum charge is 25GBP plus return postage costs.

If you have a comment about this builder's guide, or have a found a mistake in it, then please do let me know. But please do not contact me or Paul Darlow directly with questions about sourcing components or general fault finding. Honestly, we would love to help but we do not have the time to help everyone individually by e-mail.

Last but not least, can I say a big thank you to all of you who helped and inspired me. Thanks especially to all those nice people on the Synth-diy and Analogue Heaven mailing lists and at Muffwiggler.com.

Tony Allgood at Oakley Sound

Cumbria, UK
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